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Physico-Chemical Analysis of Selected Groundwater Samples in Dhamar basin area, Yemen

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ABSTRACT

In this paper, the study aims to analyze the physicochemical properties of water in the region of Dhamar (Yemen). We have chosen five Qa's (sectors) from the Dhamar Basin (*Qa 'sherah, Qa' Samah Qa 'Balasan, Wadi Almawaheb, and Qa' Asawad*). The physicochemical parameters such as T°, pH, EC and TH and the major ions Na^+, k^+ Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, HCO_3^- were evaluated in 60 wells: the temperatures recorded in the waters vary between 20 and 41 °C, the temperature (> 30°C) was found mainly in *Wadi Almawaheb* and in some parts of *Qa 'Balasan*, this indicates that the boreholes are located in a volcanic zone, however the pH of the groundwater is alkaline and in accordance with the standard; Compared to Yemen standards, While that salinity, major ions concentrations, and total hardness are normal in all four *Qa's* boreholes (*Qa 'Balasan, Qa' Samah, Qa' Sherah, and Qa' Asawad*), whereas they are abnormal in *Wadi Almawaheb* due to the impact of sewage from the city of Dhamar. The correlation coefficients of the TH and EC variables are strongly correlated with all the parameters except the pH, T° and K. The principal component analyzes (PCA) show a total variation explained by each parameter with the wells, we found that 6 wells are polluted at *Wadi Almawaheb* at all chemical parameters except potassium, this complies with the laboratory analysis. Hydrogeological assessment of groundwater indicates dominance of Ca^{2+}> Na^+> Mg^{2+}> K^+ and HCO_3^-> Cl^- >SO_4^- and the dominant type of groundwater is 48% cation and anion mixture, 30% HCO_3^--Ca^{2+} 7% HCO_3^--Na^+ and 15% Cl^--SO_4^{2-}-Na^+ respectively, this indicates that the groundwater type is a dissolution of a mixture of dolomite, CaMg (CO3), gypsum ($CaSO_4$ $2H_2O$) and Halite (NaCl). Irrigation evaluation parameters are sodium adsorption rate (SAR), residual sodium carbonate (RSC) or Na% and electrical conductivity (EC), permeability index (PI), sodium content (SC) and EC with SAR. They show that water can be used in agriculture in *Qa 'Sherah, Qa' Samah, Qa' Balasan and Qa' Asawad* except at *Wadi Almawaheb* and according to the US Salinity classification, the samples studied are classified as follows: 75%, C2- S1, 1.7% C2-S2, 15% C3-S1, 5% C4-S1 and 3.3% C4-S2.

Key words: Groundwater, physicochemical characteristics, PCA, ArcGIS.

INTRODUCTION

Cleaning the water is one of the essential processes that profoundly influence this life. The deficit of cleaning water increases day by day due to over pollution and pollution of water (fast growth of industrial activities) so the drinking water analysis for physical, chemical properties are very important essential for public health studies (Rafiullah et al., 2012, Bakraji et al., 1999, Kot et al., 2000). The existence of water has always been the

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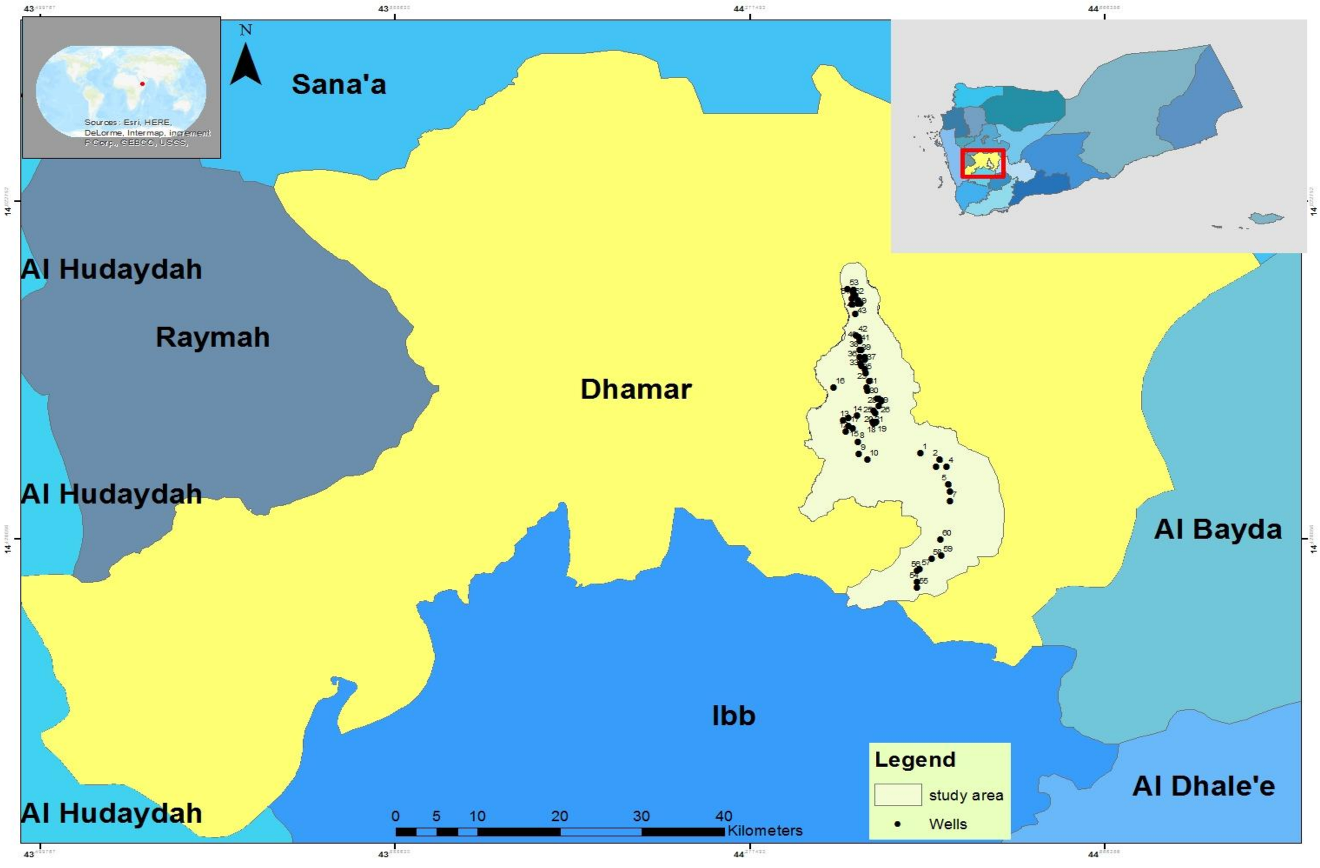
essential source of life for a majority of living organisms. The modern civilization, industrialization, urbanization and increase in population have lead to fast degradation of our ground water quality. The problems of groundwater quality are much more critical in areas which are densely populated, with localization of industries. Water for human consumption must be free from organisms and chemical substances in concentration large sufficient to affect health (Gray, 2008). The addition of various kinds of pollutants through sewage as (industrial effluents, agricultural runoff …etc) into the water main stream brings about a series of changes in the physicochemical and characteristics of the water, which have been the subject of numerous investigations (Vollenweidre, 1986). Subsequently approximately 70% of the earth's surface is covered with water, that’s why it's called the blue planet, 97.2% of the water of this planet is salt water (oceans and seas). However, less than 3% of the total volume of water on earth is gentle. Two thirds of this fresh water is in the solid state (ice caps, ice and snow) and finally only less than 1% of the water is soft and liquid (lakes, rivers, aquifers, etc), (Appelo, 2004).

Therefore, only 1% of the total available water can be of direct use by humans at the global level and on an annual basis. Enough freshwater is available to meet such demand, but spatial and temporal variations of water demand and availability are big, leading to water scarcity in several parts of this world during specific times of the year. The essence of global water scarcity is the geographic and temporal mismatch between freshwater demand and availability (Gleick, 2000, Caballero et al. 2006, Mekonnen and Hoekstra, 2016). Yemen is regarded as one of the countries of scarce water due to its geographical location within the arid and semi-arid region, where groundwater depletion has become a critical issue. Since the 1980 in Yemen, particularly after farmers rapidly exploited the groundwater resources through excessive drilling of deep wells, there are an estimated 50.000 wells across the country and more than 381 drilling companies with about 656 drilling rigs, only about (20%) of these operating rigs are currently officially registered. About (91%) of the water resources is employed in agriculture and the balance is used for domestics and (9%) for industrial purposes. Water requirements are expected to reach 26.2 BCM by the end of the twentieth century, and 36.7 BCM by the year of 2025 (Stroeve et al. 2008, Odhiambo 2016, Al Ansari 2013, Mark et al. 2012).

The pollution of water issue is a considerable problem from two perspectives: ecological and health-threatening pollutants. Growing introduction of human sewage, industrial effluent and agricultural runoff to streams, wetlands, beaches and coastal waters has increased pollutants in the environment, Indiscriminate discharge of human sewage and industrial wastewater into absorption wells and surface water in residential areas and industrial sectors. On the one hand has led to the

Figure-1. Location diagram of study area



increase of harmful substances in the aquatic environment excessive to the environmental standards

and on the other hand, improper use of such wastewater in agriculture, finally leads to the arrival of the contaminants in food sources of the population (Fani 2016). Yemen has made rapid population growth during the last decades, where water and food security are the major challenges. The current annual population growth rate of 3.7% is considered one of the highest rate in the world. It is expected that the present population of about 25 million will increase to about 37.9 million in 2021 and 53.4 million in 2031 (Glass 2010, Van 2012). It has seen a big influx of people from rural areas and they can barely cope with insufficient water supply to all inhabitants. The access to safe water is still low in Yemen, where 56% of the urban population and 45% of the rural population having such access supply in 2007 (Kuster 2011). The objective of the present study is to analyze and assess the physio-chemical parameters of the groundwater samples collected from 60 wells in Dhamar basin, Yemen.

MATERIALS AND METHODS

Study area:

The study area is located in Dhamar Basin (represents *Qa' Sherah, Qa' Samah, Qa' Balasan, Wadi Almawaheb and Qa' Asawad*), which is about one hundred kilometers south of the capital Sana'a, where it is situated between 1595000 at 1630000N and 421000 at 456000 E (Figure 1). It is located at an average elevation of 2400 m, and covers an area of 500 km^2 with a population of more than 100.000 (Al-Kohlani 2009, Al-Dawsari 2012).

The geology of study area includes quaternary alluvium, tertiary and quaternary volcanic formations including basalts, rhyolites, and ignimbrite ash streams with occasional granite intrusions (Minissale et al. 2007, Sporry 1991). Dhamar basin is a relatively flat area due to the presence of a NNW–SSE graben partly filled by alluvium and quaternary pyroclastic and the two more recent rhyolites volcanic cones merge from the plateau near the villages of Al Lisi and Isbil these rocks were intersected by obscured flare defects generally operating

in the southern northerly direction, tertiary basalts in the northern regions (Grolier et al 1984, Overstreet et al. 1985).

According to Bruggeman (1997), the study area two distinct rain seasons, separated by a distinct dry interval (mid-May- mid-July), the first rainy season start in mid-March - early April, the second rainy season begins in mid-July-early August and stops abruptly in late August, the months of September to February are usually dry, although occasional thunderstorms can cause rain during these months. Where the rate of precipitation during 1999-2016 is about 407 mm/year, with regard to the large depressions to the east and north-east room and the distribution of monthly precipitation shows that most precipitation amounts precipitated within five months most of which happen in March, April and May and the other higher amount occurs in July and August. The Dhamar zone is affected by moderate weather conditions, while the maximum average annual temperature during the period 1999-2016 was about 24.4°C, as much as the average direct surface relay surface water during the rainy season, while that most evapotranspiration of rainwater (about 90%), to the atmosphere only 10% of the total precipitation infiltrate into the groundwater recharge and forms the runoff part.

Table-1. Statistical analysis of water samples for the study area and compared with YEMEN standards

Parameters	Mean	S.D	Min	Max	YEMEN Standards	WHO
T	26.21	3.85	20.00	41.50	25	25
pH	7.61	0.38	7.00	9.20	6.5-9	6,9-9,2
EC	871.47	1101.61	329.00	6327.00	450-2500	500-1500
Na^+	68.26	79.38	16.10	460.00	200-400	200-600
K^+	5.69	5.33	0.39	23.46	8-12	20
Ca^{2+}	70.78	108.70	4.01	591.18	75-200	75-200
Mg^{2+}	27.61	38.40	2.43	231.04	30-150	30-150
Cl^-	106.60	118.81	6.03	537.93	200-600	250-600
SO_4^{2-}	101.19	172.56	7.09	1104.69	200-400	250-600
HCO_3^-	234.82	276.96	48.81	1531.35	250-500	500
TH	290.17	423.87	40.03	2224.81	100-500	100-500

Groundwater and rain are the only source for irrigation and domestic use in the study area.

Methodology:

Sixty water samples were collected from wells throughout of the study area as mentioned on (Figure 1). All samples were collected in the period between December 2015 and August 2016, the samples were taken after pumping for 10 min. Clean and dry polyethylene bottles were used to collect the samples following the standard properly labelled and refrigerated procedures prior to analysis for different quality parameters (Girard 1975). The samples were transported in a fresh box and stored at a proper temperature until analysed in the laboratory of the Agricultural Research and Extension Authority in DHMAR City, YEMEN. After samples collection the

electrical conductivity, total solid substance and temperature were measured in the field using a CEL/850 Medium Conductivity Session (HACH), in the laboratory, temperature was also taken for all samples to be analysed of the chemical parameters: Ca^{2+}, Mg^{2+}, Na^{+}, k^{+}, Cl^{-} and HCO_3^{-1} using the analytical method proposed for the World Health Organization (Lenore et al.1998,WHO 2003), while Ca^{2+} and Mg^{2+} were measured using 0.02 N EDTA and the concentration of HCO_3 and Cl^{-} by titration $H2SO_4$ and $AgNO_3$ respectively, whereas the concentration of Na^{+} and K^{+} were measured by a flame photometer (PFP 7), the pH value is measured directly by a pH-meter (WTW422).

The statistical analysis treatment was carried out using statistical package for facial sciences (ArcGIS13.2, origin 2017 4, aquechem 2014 & programme10).The statistical and geostatistical methods were selected because of the strong capacity to characterize the special variation for different parameters from the quality of the groundwater, where it was utilized following and The Principal component analysis (PCA) was used to analyze the correlation structure between the set of groundwater quality parameters collected during the survey (Joinet al. 1997). The development of the map of study region were performed using approach integrated in the Geographic Information System (GIS) by the software ArcGIS 10.3 version ArcGIS10.3 based groundwater quality mapping for drinking water.

RESULTS

The results of the calculation of the statistical parameters representative of the 60 samples (observations) and the 11 variables are given in Table-1, its was compared with the World Health Organization and the Yemen standards for drinking water (WHO, 2011. NWRA 2000).

Water temperature is very important because many of the physical, biological and chemical characteristics are directly affected by temperature (Patil et al. 2012; Chapman and WHO 1996). the result of the field temperature in table -1 ranged for all wells between 20 to 41.5 ° C with mean value of 26.21 ± 3.85 and it was the highest temperature 41.5 in the well-24, because it is located in a volcanic area, the pH indicates the strength of the water to react with the acidic or alkaline material presents in water, which controls by the CO_2, CO_3^{2-} and HCO_3^{-}concentrations (Hem 1991).

Figure-2. The map of spatial distribution of the pH on study area.

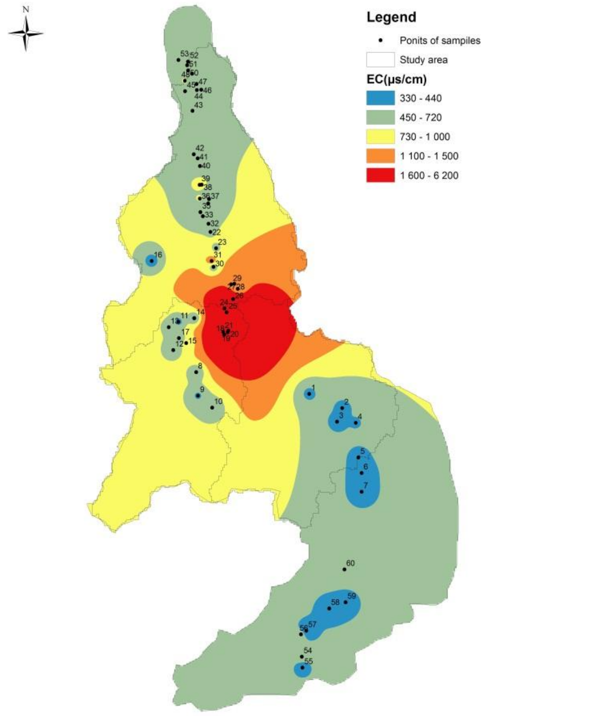


Figure-3. The map of spatial distribution of the EC on study area.

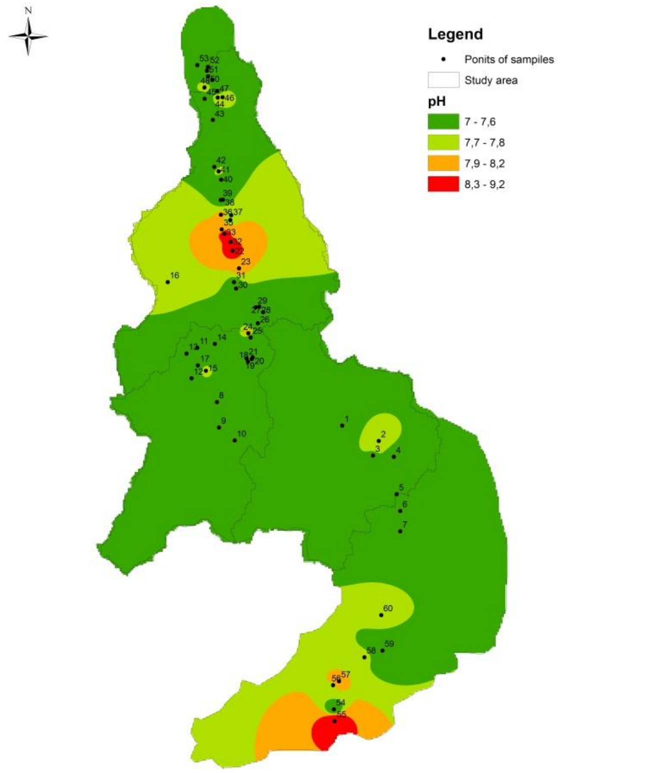


Figure-4. The concentration of major cations.

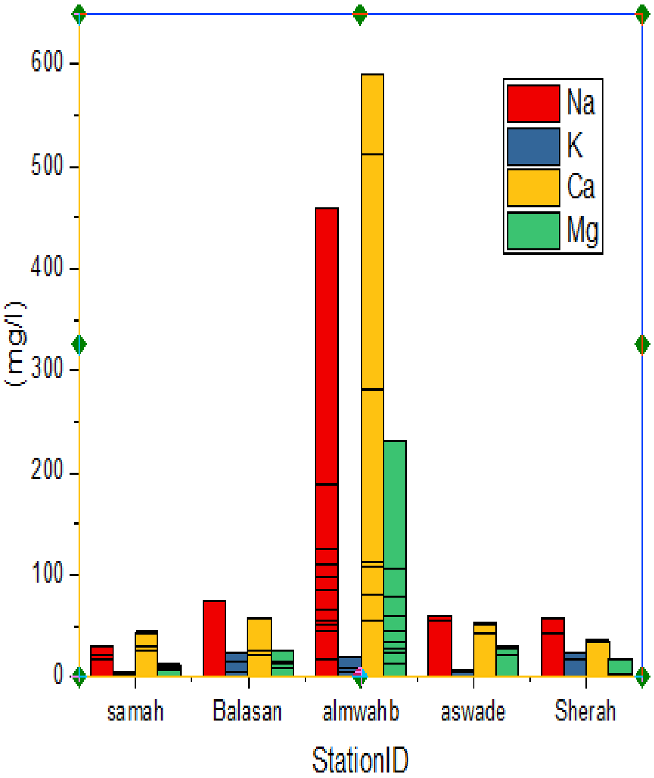


Figure-5. The concentration of major inions

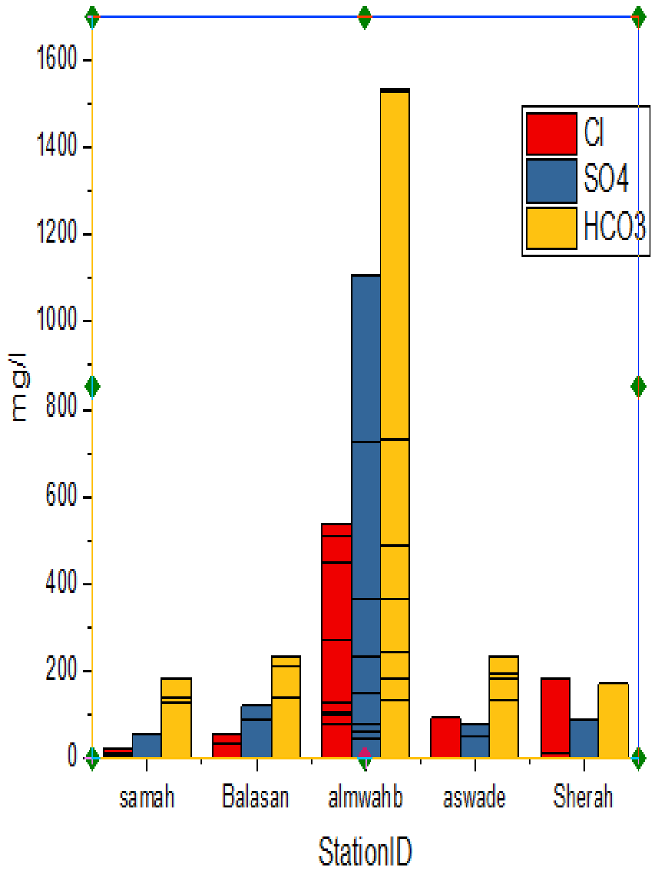
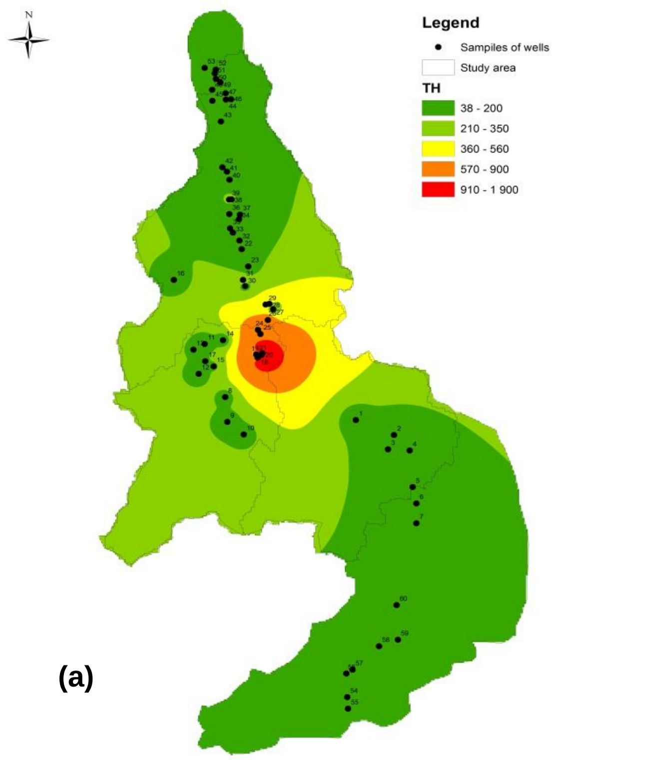


Figure-6. The map of spatial distribution of concentration (a) and histogram (b) for all samples



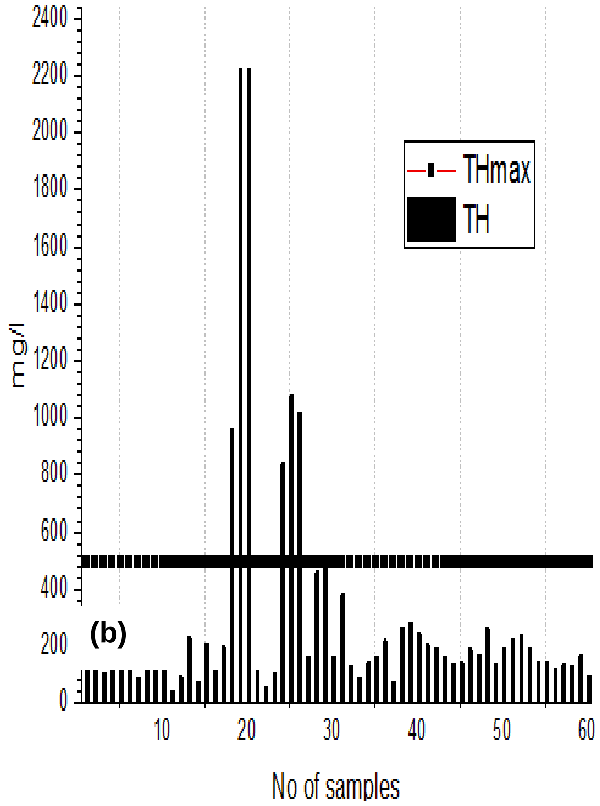
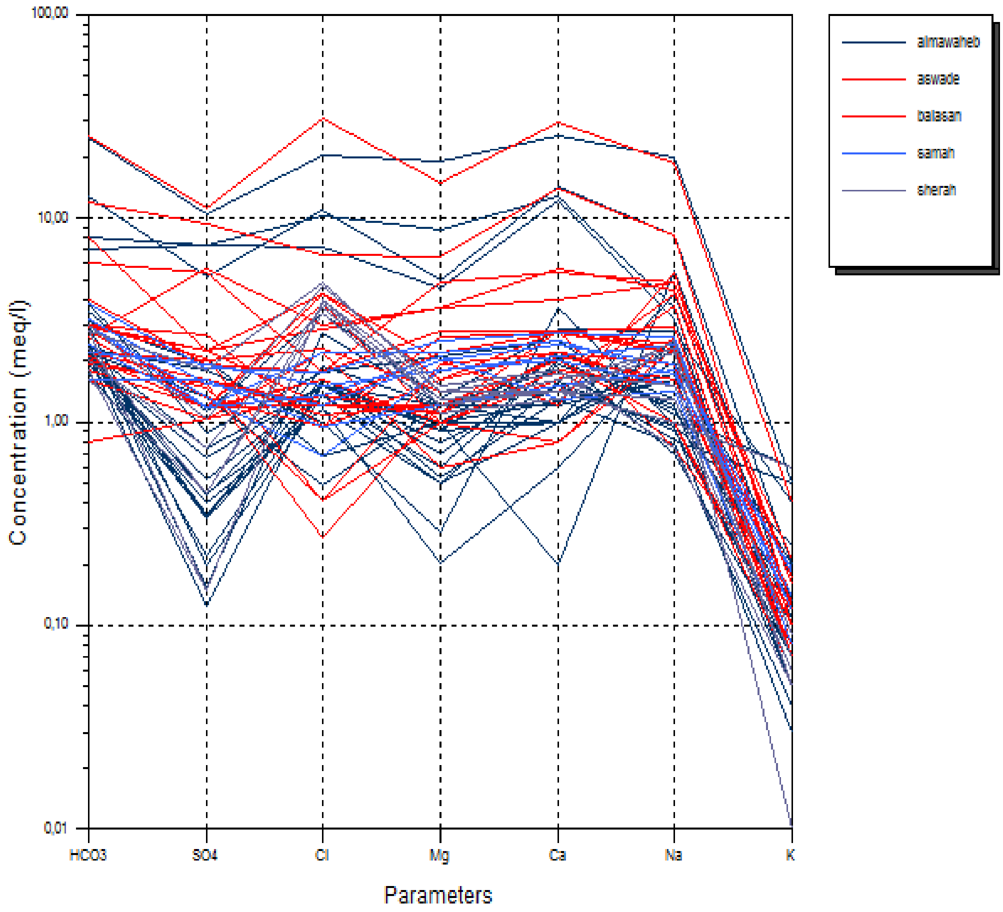


Figure -7. Schoeller diagram of all samples



While the result of The pH in Table -1 and Figure-2 of the study samples ranged between 7 to 9.2 with a mean value of 7.2 ± 7.61 indicating alkaline groundwater in nature except well-55, and compared with Yemeni standards it's located within the permissible limits, the electrical conductivity (EC) indicates the amount minerals dissolved in water of study area in Table-1 and Map-3, it is ranging from 329 to 6327 µS/cm with a mean value of 3018.65 µS/cm, values obtained in the most study area are fresh water in comparing Yemen standards except the high salinity ratio of the upper limit of the standard in the area of Almawaheb compared to the rest of the regions because
of the impact of the wastewater station on them, as well as a non-treated sewage outlet in the top of the valley, where they pose a major threat to the degradation of natural resources in the region and which are directly affected by human activities.

The results of ions major are given in Table 1, Figure-4 and Figure-5, the concentration of main cations calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{2+}) and potassium (K^{+}) and large anions (bicarbonate(HCO_3^{-}), chloride (Cl^{-}) and sulfate ($SO4^{2-}$) were measured in a total of 60 groundwater samples, the concentration of calcium (Ca^{2+}) is ranging from 4.01 to 591.18 mg/l with mean value of 70,87±108,7, The concentration of magnesium(Mg^{2+}) is ranging from 2.34 to 231.04 with mean value of 27.61±38.40, the sodium (Na^{2+}) concentration is ranging from 16.1 to 460 mg/l with an average value of 72.12±83.61 and the concentration of potassium (K^{+}) is ranging from 0.39 to 23.46 mg/l with mean 5.69 ±5.33, the results of major cations is compared with the Yemeni standards for drinking water indicate in Table-1 and figure-4, a significant increase in major cations concentration in the wells near the wastewater station in Almawaheb region because the impact of wastewater treatment plant on this wells.

Table-2. Matrix correlation of 11 physicochemical parameters

	Temp	pH	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-	TH
Temp	1,00										
pH	0,19	1,00									
EC	-0,31	-0,10	1,00								
Na^+	-0,19	0,02	**0,94**	1,00							
K^+	-0,08	0,00	0,34	0,35	1,00						
Ca^{2+}	-0,38	-0,13	**0,99**	**0,89**	0,33	1,00					
Mg^{2+}	-0,31	-0,13	**0,96**	**0,91**	0,35	**0,94**	1,00				
Cl^-	-0,36	-0,12	**0,98**	**0,94**	0,36	**0,97**	**0,95**	1,00			
SO_4^{2-}	-0,17	-0,08	**0,93**	**0,83**	0,25	**0,91**	**0,89**	**0,86**	1,00		
HCO_3^-	-0,34	-0,08	**0,94**	**0,88**	0,38	**0,93**	**0,88**	**0,91**	**0,78**	1,00	
TH	-0,36	-0,13	**0,99**	**0,91**	0,34	**0,99**	**0,98**	**0,98**	**0,92**	**0,92**	1,00

Major anions (Cl^-, $SO4^{2-}$, HCO_3^-) are naturally very variable in surface and groundwater due to local geological, climatic and geographical conditions (Chapman and WHO 1996). The results of the major anions in Table-1 and Figure-5, the concentration of chloride (Cl^-) is ranging from 6.03 to 537.93 mg/l, with mean value 106.60±118.81,where the concentration of sulfate (SO_4^{2-}) is ranging from 7.09 to 1104.69 mg/l with mean value 101.19 ±172.56 and the concentration of bicarbonate (HCO_3^-) is ranging from 48.81 to 1531.35 mg/l, with mean value 234.82±276.96, the results indicate a significant increase in the concentration of ions in the wells located in the Al-mawaheb area, especially the wells located near the sewage station to compared by the Yemeni standards. Without forget that the hardness measurements are a very important property for domestic and industrial water quality classifications, the total hardens (TH) is dependent mainly on the presence of alkaline earths, Ca^{2+} and Mg^{2+} (WMO 1977). While the result of the concentration of total hardens (TH) is ranging from 40.03 to 2224.81 with mean value 290.17±423.87, the classification of the groundwater of the study area based on hardness has been carried out and is presented in Table-1, according standards Yemen 54 of samples (90%) fall under the hard and 6 of samples (10%) fall in very hard category (Figure -6 (a),(b)).

Representations of Graphical:

This purpose, different collective diagrammatic representations of the quality variables are suggested in the literature, it is necessary to decide about the quality, suitability, and convenience of groundwater for different objectives.

Schoeller Diagram:

The schoeller Diagram is for groundwater quality concentration representations according(Schoeller1967), where on the horizontal axis anions and cations are shown in sequence with their equivalent per million (meq/l) amounts on the vertical axis logarithmically (Figure-7). The reason for logarithmic scale is for rather uniform distribution appearance of ionic concentrations, where the domination of ions Model samples of groundwater were Ca^{2+}> Na^+> Mg $^{2+}$> K^+ and HCO_3^-> Cl^- > SO_4^{2-}.

Piper Diagram:

The piper diagram is one triangle can hold at the maximum three variables as it has three axes, and therefore, on the whole association of six different variables is possible (Piper 1944). In plotting three cations (Ca^{2+}, Mg^{2+} & Na^++ K^+) expressed as percentages of total cations in meq/l and hence, a single point is obtained on the cations triangle. The triangle other is for anions (SO_4 $^{2-}$, Cl^-, HCO_3^-) in the same way (Figure 8). However, these two points each within the triangles are projected into a central diamond (rhombohedra rectangular) shaped area by parallels to the upper edges of the central area. It is obvious from Figure 8, these hydrofacies are established from the dominant anion and the dominant cation, most groundwater was mixes cations and anions, 18 of samples are Ca^{2+}+ HCO_3^-type, 4 of samples Na^++ HCO_3^- and 9 of samples Cl^-+SO_4^{2-} $^+Na^+$, Where the water is calcium carbonate type of fresh water. this indicates that the groundwater type is a dissolution of a mixture of dolomite, CaMg (CO3), gypsum (CaSO4 2H2O) and Halite (NaCl).

The correlation coefficient:

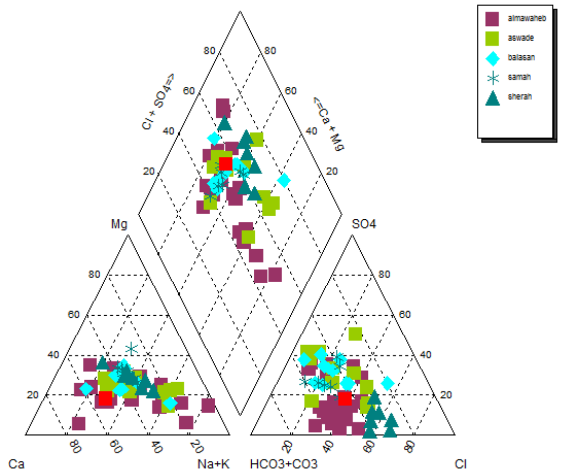
Correlation matrix of 11 physicochemical parameters of study area is presented in Table 2. It could be seen that some mineral components like correlation's coefficient TH and EC variables are highly correlated with all parameters except pH, T C° and K pointing out to different origin.

Principal component analyses:

The principal components were extracted by the R-mode principal component method, which mathematically transforms the original data with no assumptions about the form of the covariance matrix, where Principal component analysis was carried out on a data matrix consisting of 60 lines representing prospected wells and 9 columns representing physico-

chemical variables measured or analyzed (Table 1). The objective of the analysis is to obtain a small number of linear combinations of the 9 variables that account for most of the data variability, from (Table 3), Figure-9, the first factors explain more than half (84 %) and the second factor represent (1%) of the variable respectively. Thus, they both accounted for more than 85% of the variable. The numerical results of this PCA show that the first component, which represents 84% of the captured variability, contrasts with the positive (CE), (Ca^{2+}), (Mg^{2+}), (Na^{+}) (K^{+}), (HCO_3), ($C1^{-}$), and (SO_4^{2-}), the second component with 0.9% of the captured variability, mainly opposes K+ which contribute positively to the expression of this axis. In contrast to the K+ which is negatively correlated with this axis (Figure. 7 (a) and (b), Table 3 and 5). According to Figure 9 shows total variation explained by each parameter with the wells, it is observed 6 wells pollution by all the chemical parameters except the potassium.

Figure-8. Piper Diagram of samples



Suitability of water for irrigation:

The suitability of water for irrigation depends upon (salinity) and the sodium content in relation to the amounts of calcium and magnesium, where the suitability of groundwater for irrigation use was evaluated by calculating Sodium adsorption Ratio (SAR) according to (Richards 1954), Sodium Content (SC) classification is given by (Wilcox 1955), Residual Sodium Carbonate (RSC) or Percentage of Na% content is a parameter to assess its suitability for agriculture purpose according to (Wilcox 1948, Richard 1954), Permeability Index (PI) according to (Doneen, 1964) and EC together with SAR determine whether groundwater can be used for agricultural purposes according a (USSL 1954), further the results of the analyses were interpreted using graphical representations like United States Salinity Laboratory (USSL) and Doneen plots.

Sodium adsorption Ratio (SAR) is a measure of alkaline / sodium risk for crops ,the water quality in the study area, it is having SAR values less than 10 are considered excellent, 10 to 18 as good, 18 to 26 as fair, and above 26 are unsuitable for irrigation use (Todd 1980) in table-6. From table -5 figure-10, the SAR values of the groundwater samples in the study area are ranging from 0.5 to 7, The SAR values of the water samples of the study area are less than 10, and are classified as excellent for irrigation, where the SAR values are less than 10 can thus, be graded as excellent for irrigation use.

Figure 9-(a): Scree plot of the 9 experimental variables

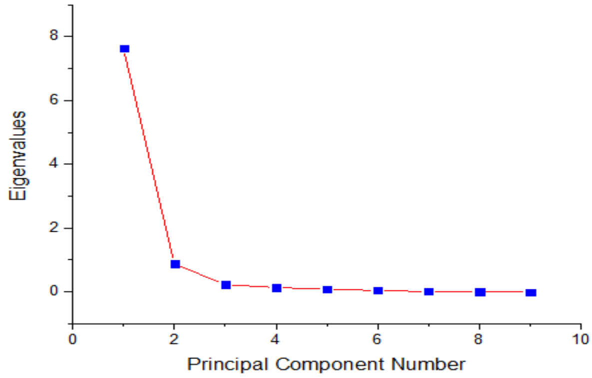


Figure 9-(b):and loads of all the samples on the plane defined by the main components 1 and 2 obtained by the 9 experimental variables

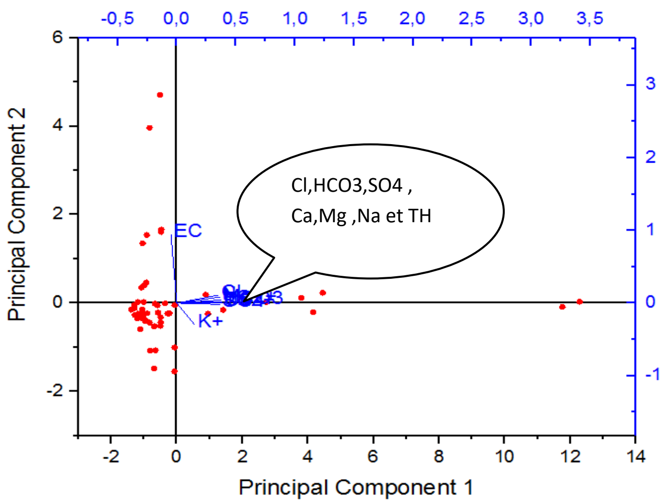
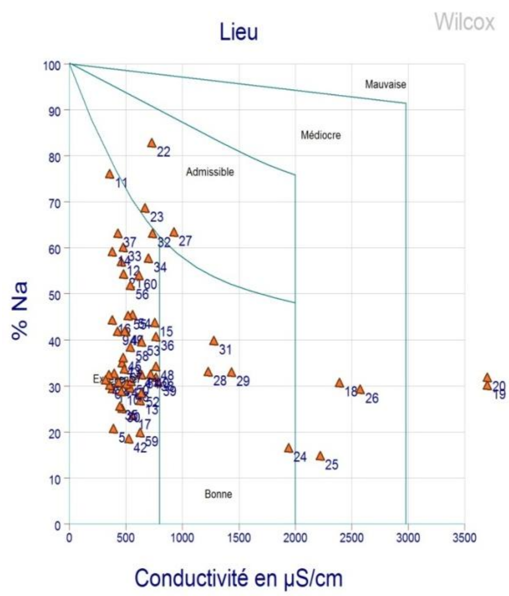


Figure-10. The quality of groundwater in relation to EC and %Na (Wilcox diagram1955).



La concentration d'ions de sodium est importante car il entraîne une réduction de la perméabilité du sol en remplissant partiellement l'espace vide. Sols avec du sodium et du carbonate sont appelés alcalins par rapport aux sols salins dans lesquels le chlorure et les sulfates sont les anions dominants. The map of spatial distribution of SC or Na% percentage in table-5 and figure-12 are ranging between 14.5-32.5 white mean 38±14.5, according to (Wilcox 1955) in table-6 maximum 15% of Na% in groundwater is allowed for agriculture purpose, 45% samples fall in doubtful region and remaining 40% is unsuitable category according to and According by (Eaton 1950) classification also results 50% of groundwater are safe and 10% are unsafe.

The plot of sodium percent-Electrical conductivity as proposed by (Wilcox 1955) in table-6, maximum 88.7% of samples in excellent region, 6.7% samples fall in good region and remaining 5% is permissible, 5% poor category 3.3% in groundwater is not allowed for agriculture purpose (figure-13).

Permeability index (PI) is proposed to classify water for its relevance in irrigation activities and it is defined terms of Na+, Mg2+ and HCO3-, from the Table-3 and Figure-14 , the values of PI are ranging between 25-118.05 meq/l, with mean 65.8±17.9, the groundwater that present 73.3% from the study area can be classified as good class for agricultural use where, the PI values are between 25 and 75, they indicate good quality of water for irrigation, and 26.7% of sampiles were can be classified as excellent class, the PI values > 75 indicate excellent quality of water for irrigation according (Doneen 1964) in table 6.

Figure-11. The map of spatial distribution of SAR

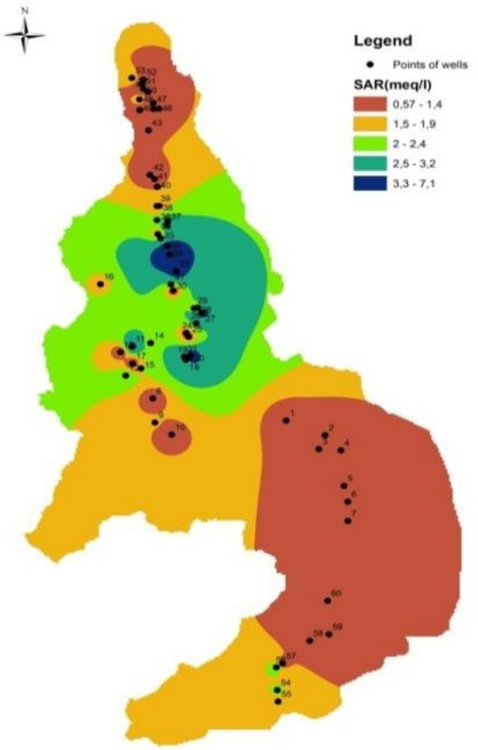


Figure-12. The map of spatial distribution of SC or % Na^+

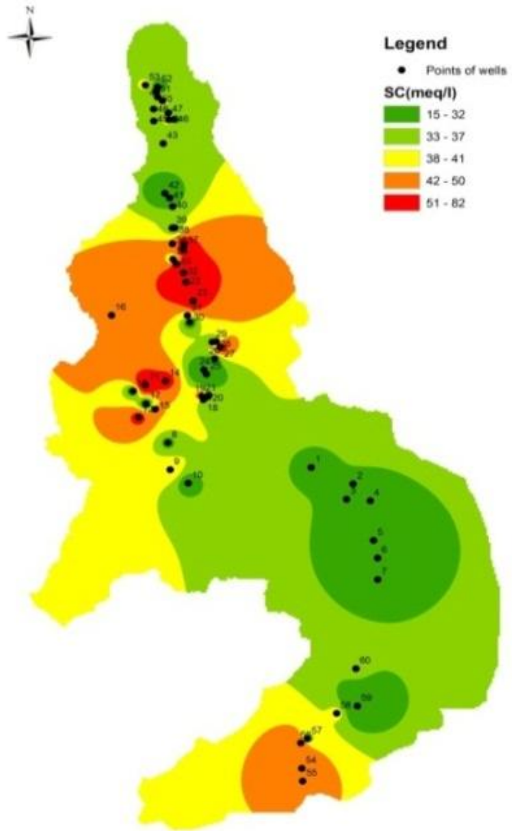


Table-3. Total Variance Explained by each parameter

	Eigenvalue	Percentage of Variance	Cumulative
1	7.62486	0.8472	0.8472
2	0.87904	0.0977	0.9449

Table-4. Charges principal components 1 and 2 of 9 experimental.

A	Coefficients of PC1	Coefficients of PC2
EC	0,36	-0,05
Na^+	0,34	-0,01
K^+	0,15	0,97
Ca^{2+}	0,36	-0,07
Mg^{2+}	0,35	-0,04
Cl^-	0,32	-0,20
SO_4^{2-}	0,35	0,01
HCO_3^-	0,36	0,00
TH	0,36	-0,06

Figure-13. The map of spatial distribution of PI

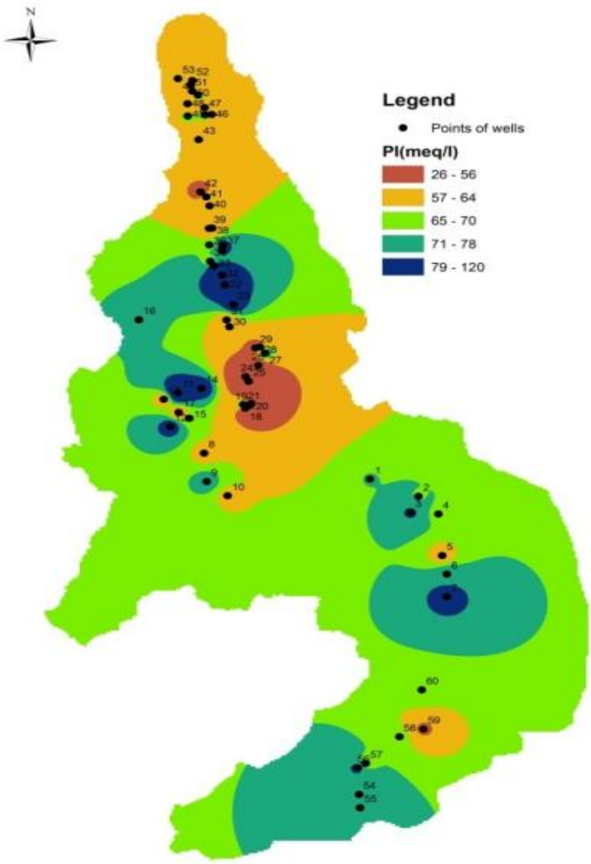
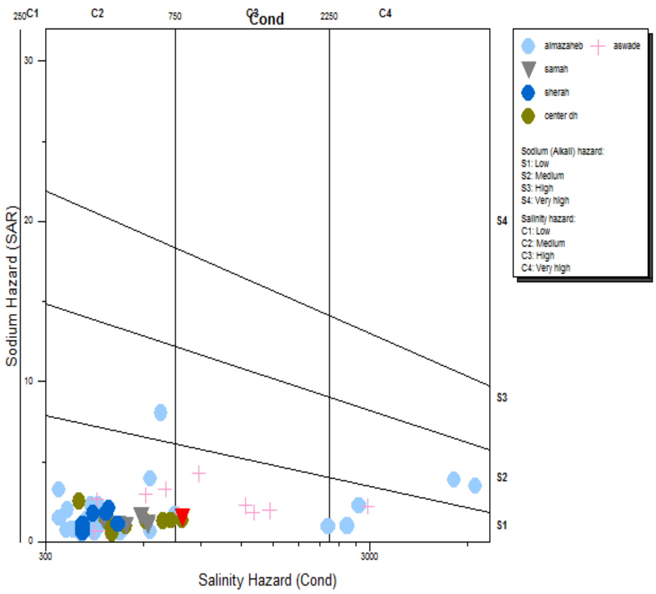


Figure- 14. The quality of groundwater in relation to EC and SAR for all samples in a USSL 1954



The bicarbonate content of groundwater is expressed as residual sodium carbonate (RSC),The value of RSC was less than 2.5 in the table-5, however by according to (Richard 1954, Lingaiah et al, 2014) classification in table-6, water with RSC greater than 2.5 meq/l is considered unsuitable for irrigation, because it causes reduction of the soil permeability by filling partially the void space, the `map of Spatial analysis showed that there no significant variation of RSC distribution in studied samples, the highest value of RSC was found in Wadi Almawaheb of the study area (figure-14).

Table-6. Hydrogeochemical classification of some important parameters indices for rating water quality and its suitability in irrigation use of study area.

Name of Category	Category	Grade	N=60	%	Name of Category	Category	Grade	N = 60	%
SAR (meq/ l) (Todd, 1980)	Excellent	<10	60	100	RSC.(meq/l) ((Richards 1954)	Good	<1.25	59	98.3
	Good	10-18	0	0		Medium	1.25–2.5	1	1.7
	As fair	18-26	0	0		Bad	>2.5	0	0
	nsuitable	>26	0		PI(meq/l) (Todd 1980)	Unsuitable	<25		0
Na % (Wilcx1955)	Excellent	0–20	49	80					
	Good	20–40	4	6.7		Good	25-75	44	73.3
	Permissible	40–60	3	5		Excellent	>75	16	26.7
	Doubtful	60–80	3	5	EC (µS/cm) (Richard, 1954)	Low salinity	0–250	0	0
	Unsuitable	>80	2	3.3		Medium salinity	251–750	48	80
Na % (Eaton 1950)	Safe	<60	58	96.7		High salinity	751–2250	6	10
						Very high salinity	>2250	6	10
	Unsafe	>60	2	3.3					

EC with SAR determines whether groundwater can be used for agricultural purposes, the relationship of SAR (alkali hazard) and EC (salinity hazard) is plotted in a (USSL 1954, Prasad Paindla et al, 2014) to determine the adequacy of water for irrigation (Figure-10), EC with SAR of study area samples are the next categories C2-S1, C2-S2, C3-S1, C4-S1 and C4-S2 with 75%, 1.7%, 15%,5% and 3.3% of the wells, respectively. Most samples are able to irrigate only C3-S1, C4-S1 and C4-S2 samples, according to the US Salinity Laboratory this type of irrigation water is considered to be very low in water and this type of water Cannot be used In the irrigation of saline-sensitive crops, especially citrus, it can be used for salinity crops with high tolerance with an effective sludge network and in soils where there is no hard layers to prevent leaching.

CONCLUSIONS

The results of these studies provide some information that can be useful for the domestic and irrigation in respective water resources studies area to water pollution,

- The pH indicating alkaline groundwater in nature, and compared with Yemeni standards are located within the permissible limits.
- Compared to Yemen standards, salinity, major ion concentration, and total hardness are normal in all four Qa's boreholes (Qa 'Balasan, Qa' Samah, Qa 'sherah, and Qa' Asawad), whereas they are abnormal in Wadi Almawaheb due to the impact of sewage from the city of Dhamar.
- the correlation coefficients of TH and EC variables are highly correlated with all parameters except pH, T C° and K pointing out to different origin
- Principal component analyses (PCA) shows total variation explained by each parameter with the wells, it is observed 6 wells pollution by all the chemical parameters except the potassium.
- the parameters to assess the irrigation are sodium adsorption ratio (SAR), residual sodium carbonate (RSC) or % Na and electric conductivity (EC), Permeability Index (PI), Sodium Content (SC) and EC together with SAR, it showed that groundwater are suitable for suitable for irrigational use in Qa's four except Wadi Almawaheb the highest value of RSC and SC.

Conflict of Interests

Authors declare that there is no conflict of interests regarding the publication of this paper.

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